Chapter 2

Space Program Management

Program management has to ensure the success of a project, and therefore this is the main objective of the management team. Success is based on the industrial project and on maintaining commitments made in terms of cost estimates, maintaining time schedules and achieving results.

Program management involves all the methods and tools of project management. It can be defined as a vast range of human expertise. This book limits itself to space projects, which, due to their special nature, are essentially complex and of long duration.

The mistake most often made is thinking that management methods and tools can be acquired during the development of the project itself. This almost always leads to estimation errors and has a negative impact on the program.

Since ultimately every industrial program is essentially a human activity, and humans are at the center of the "man-technique-market" trio which pervades a project, and for this reason these management techniques evolve with man's social, industrial, and behavioral development.

Therefore, management is not an exact and unchangeable science. Generally, it can be broken down into four basic types of actions:

Planning: These activities are aimed at studying and preparing documents for establishing objectives and requirements within expected time frames. Afterwards, development plans are communicated.

Organization: These activities are aimed at adapting production structures to achieve objectives, to divide work into subsystems to reduce the overall complexity of the project, and to make work efficient.

Coordinating: These activities are aimed at directing, informing, and communicating within the structures involved, coordinating work and providing motivation.

Control: These activities are aimed at establishing rules and procedures which measure the results achieved through time so that there is an awareness of possible differences between what was achieved and what was expected to be realized at that time (Figure 2.1).

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Space Technology Library 28, DOI 10.1007/978-1-4614-3755-0_2,

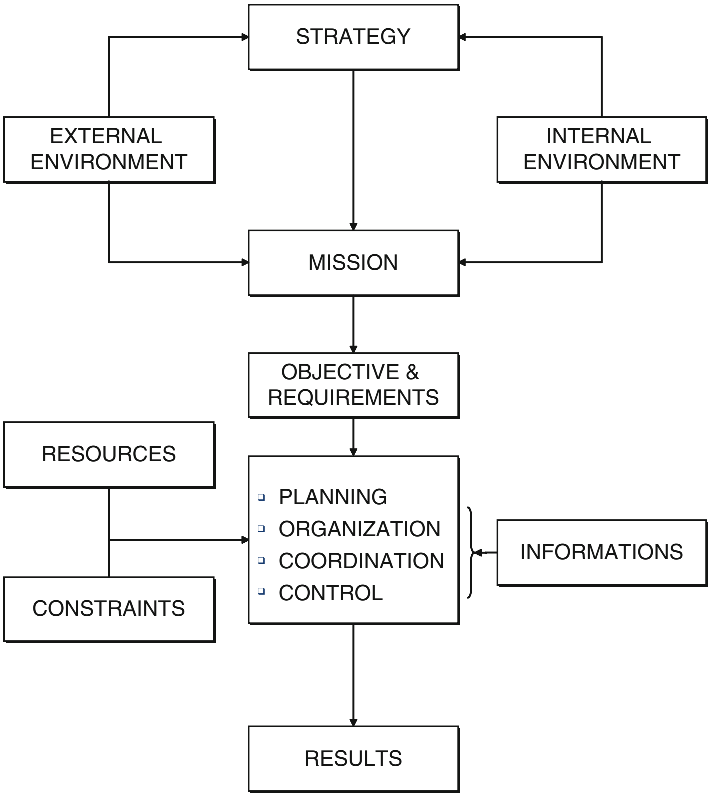

Figure 2.1. Basic management methodology flowchart.

2.1. Characteristics of Space Programs

For the most part, a space program is a major project for:

1. The development, realization, putting into orbit, and use of space systems, such as satellites, scientific satellites or orbiting infrastructures, with the aim of fulfilling the aims of the mission for which the systems were designed.
2. The development, realization and testing in flight of a launch system (i.e., a space launcher) which can put a payload (i.e., the space system referred to in point 1) into orbit.

Therefore, a space program has specific characteristics based on the type of mission to be performed. These characteristics influence the specifications and decision-making process involved in the realization process from its conception.

It is important to define a space program through an analysis of its main characteristics which can be summarized thusly:

- Strategic importance
- Extent of international participation
- Specific industrial and specialized sector
- Significantly high investment cost

- Long-term time frame program
- Rapid development, obsolescence, of the technologies used
- Impossibility of intervening in space for repairs and/or maintenance
- Use, which is often incorrectly understood and scarcely perceived outside of the framework of the specific sectors

Strategic Importance

The space sector, in addition to civilian applications, is unquestionably linked with military requirements and applications because of its history and constant technological development advancement.

The ability of satellites to fly beyond borders and their ability to connect people in different continents without using on-ground infrastructures are only two of the many reasons for their strategic and military features.

A nation's capability, or a group of nations such as Europe, to be able to design, realize, and launch space programs is an essential requirement in the third millennium in order to be respected politically and economically at the global level.

This capability is expressed in two technological areas: autonomy of access to space (ability to use one's own launcher from their homeland) and satellite technology availability. This can be traduced in having an industrial sector capable to design and build autonomously launchers and satellites platforms, as well as electronics on-board. Without this technological autonomy, a nation cannot consider itself a space "power."

Extent of International Participation

Quite often, because of its industrial and economic scope, a space program is implemented in the framework of international cooperation. In addition, a space program operates in extra-atmospheric space and therefore the entire human community can be involved both negatively and positively.

It should be pointed out that when space technologies began in the 1950s and 1960s, the programs were developed exclusively on a one-nation basis, in the USA and the former Soviet Union. Since there was a strategic, political, and military competition between the two blocks (West and Soviet) behind all programs, space was mainly a theater for tactical confrontation.

There has always been a spirit of collaboration among nations since the 1960s in Europe and the creation of the European Space Agency (ESA) is a proof of this. The Member States are committed to creating a supranational organization charged with developing space programs for peaceful purposes, that is, for knowledge and the common good.

Obviously, ESA has not stopped the national space agencies of the major Member States, France, Germany, and Italy, which altogether have contributed approximately 60% of ESA's budget, by designing and realizing nationally based or bi-multilateral-based programs.

However, what is brought to the forefront of discussion in this book is space's international character which is not only political and dimensional, but also technical.

The international aspect is already significant during the technical definition of a space program: the fallout of a launcher's stages in the sea or on land, the reentry of satellites into the Earth's atmosphere (or the Space Shuttle), global coordination of

the use of radio-electrical frequencies for satellite transmission and reception, crowding and overcrowding of orbital spaces on local or global geographical areas, limitations on the use of onboard satellites of radioisotope power generators, limitations on the coverage from space of geographical areas with radio-electric emissions.

All of these technical aspects give a limited idea of the international characteristics of a space program.

The international aspect of a space program is very often also stressed by the need to share the high costs which cannot be afforded by single nations.

Specific and Specialized Industrial Sector

From the beginning, the realization of space systems has been the prerogative of dedicated industries which during the course of many years have developed specific competences and their own development means.

This has globally brought about the creation of an industry in the broadest sense of the word, a unit of scientific and industrial entities highly focused and specialized.

This has to some extent prevented the development of a major synergy in the past between the space, aeronautical or electronic industries. However, now there is a major transfer of expertise and resources among those areas.

There continues to be specific industrial feature of the space sector, which highly defines the specialization. For example, still nowadays CPUs derived from old technology processors are installed on commercial television broadcast satellites. New CPUs such as the ones equipping home or office computers could be much more efficient; however since they must function in extra-atmospheric conditions, the qualification and testing process is such a high-level and specialized requirement that the industrial specificity has been maintained and is evolving slowly.

Significantly High Investment Cost

A space program's cost is always a major investment, whether it is funded by public funds or private capital.

In the first case, investments come from space agency's budgets, while in the second case the capital is from commercial and private companies that are investing for a profit.

For example, let's examine the Ariane 5 program, selected by ESA in 1985. This program was supposed to conceive and realize the European launcher of the twenty-first century. When it was first launched in 1996, the program had cost 6 billion euro and had been completely funded by ESA with public funds. Since the first launch failed, more years and billions of euro were needed to achieve a testing configuration of the launcher during the first part of the 2000s.

The initial decision to undertake these programs, however, was full of not easily foreseeable consequences and could only be taken at the highest level of government. In fact, the highest decision-making body for ESA is the Ministerial Council where the Research Ministers of the Member States are seated and commit their respective governments with their decisions to fund ESA's programs on a multi-year basis.

On the other hand, decisions are taken by the Board of Directors of the companies which intend to start up a space program for profit in the case of private commercial concerns.

This is why the manufacture, launch and operations of a television broadcasting satellite can last 15 years and can cost a minimum of 200 million to a maximum of 500 million euro, depending on the satellite's size and the number of transponders it contains.

Another example is the private commercial initiatives involving telephone communications satellites that were realized in the 1990s, Iridium and Globalstar for example, which cost private investors up to 9 billion euro.

The large amount of investment required is because a space program is so complex that it involves many partners at all levels and requires specialized industries which only five or six countries in the world possess.

Long-Term Time Frame Program

Generally, it takes more than 10 years between the first preliminary studies on a space system and the end of operational services and sometimes, in the case of launchers or the International Space Station (ISS), even more than 20 years.

Sometimes the development of satellites, for example European weather satellites, can last 20 years before evolving to the subsequent generations. The American satellite system Global Positioning System (GPS) for navigation and localization, began its first feasibility studies in the 1970s and became operational during the first war in the Persian Gulf in 1991. In 2008, the American Defense Department began the development of third-generation GPS satellites to ensure both the renewal and evolution of the system.

From these and other examples, the importance of outlook and vision when undertaking a space program is understood. This is also necessary because sometimes it is difficult to be aware at the start-up of broader uses of the system.

Rapid Development, Obsolescence, of the Technologies Used

The technologies used for space programs have evolved extraordinarily in the last 40 years. Astronauts of the Apollo Moon missions of the 1960s did not have the computing capability on board their spacecraft, which is now available in a Personal Communication Device, such as a notebook, or laptop or multifunction cellular phone.

The onboard software of the Moon-landing module used about 20,000 lines of instructions. Today, any smart-phone contains software with millions of lines of instructions.

For this reason the choice of technologies used in space program missions remains an exercise in caution and balance since the directions taken will influence the program during its entire operational life.

The technological level acquired at any given point in time can influence the choice of a space program in at least two obvious cases:

- A technology which is not immediately available but only after a research and development phase could be a handicap to the development of well-identified applications.
- On the other hand, a technological advancement could have a flywheel effect for a program with a greater future outlook for its applications.

Impossibility of Intervening in Space for Repairs and/or Maintenance

Despite the promises of the past decades to operate in space in an "ordinary" way, this is still not the case. Therefore, 99% of the time it is impossible to repair a breakdown which occurs while the satellite is in orbit.

The remaining 1% possibility is for very special missions such as NASA's Hubble space telescope which was repaired in orbit by American astronauts. Once they reached the Space Shuttle at over 600 km in altitude they repaired it, performing the necessary modifications to restore focal balance to the lenses, every 8 or 9 years. However, the mission was complex and costly and was only carried out because Hubble's orbit could be reached and it cannot be overlooked that billions of dollars invested by NASA would have been wasted once the focusing defect of the lenses was noted soon after the start-up of the space telescope's operation.

Obviously, this case is quite out of the ordinary, in addition since the Space Shuttle has been phased out in 2011 no one will reach the Hubble Space Telescope anymore.

In the case of commercial telecommunication satellites which orbit at 36,000 km altitude, any attempt at repair or maintenance to date can theoretically be done but operationally has never been developed.

Minimizing breakdowns is reduced with in-flight experience of pre-operational satellites or during testing, whenever possible, in order to learn how to improve the production process on ground.

Use, Which Is Often Incorrectly Understood and Scarcely Perceived Outside of the Framework of the Specific Sectors

Despite the growing importance of the uses derived from space systems in the last 40 years, the potential benefits from this sector often remain misunderstood not only by a large number of people who are not involved in making them, but also sometime by politicians in charge who are ultimately the ones to decide on the amount of public investment to be made in the sector.

In several sectors such as telecommunications or weather satellites, the use of satellites has become an integral part of the means used by public institutions or businesses and the public realize their need because of the direct advantage they benefit from (for example, satellite pay TV used by millions of European citizens and the world know the advantages of satellites).

The recent boom in the spread of GPS satellite navigators for cars and cellular phones has further drawn the public to an awareness of the use of space systems, but many of them still do not understand their use.

Space systems for Earth observation, for example, whose technological development is constantly growing, are certainly understood and used by public institutions such as military authorities, but other government agencies still do not know they could use the services provided by these systems for managing the territory, coasts, agriculture or for other socially useful aspects.

Space systems for cosmology or the study of the universe have always fascinated the public because the discoveries they make have the magic of bringing man closer to the fascinating mysteries of the stars and planets. Too often, however, this fascination is only accessed sporadically at the time of a certain media event which will remain locked in the restricted circle of the scientific community. It is also true that

the scientific discoveries of space systems of the past 30 years have allowed us to revolutionize and broaden our knowledge of the solar system as man has never been able to do in the past centuries.

An age-old debate on whether or not to develop programs with astronauts to orbit around the Earth, towards the Moon or Mars, rather than send robotic probes is also part of this misunderstanding of space programs.

The most widespread obstacle concerns the fact that beyond the strategic or political needs of a nation to affirm their own technological superiority by sending men into space (which was the basis for NASA's Apollo Moon program), there have been no significant technological advantages or knowledge to date on sending men into space compared to the enormously less expensive achievements of satellites or robotic problems.

There is no one clear answer to this debate which remains animated but incomplete, and certainly space agencies should make an effort to spread knowledge about the space sector to the greater public, but with an awareness of the possible advantages of these technologies, as well as their limits, it has the unknown elements and risks which are present in many other human activities.

2.2. Methods of Defining and Managing Space Programs

Because of its nature and obvious destination, a space program is aimed at realizing a space mission.

The necessary industrial products to be realized for this are:

- Launchers, either reusable and expendable satellites or space probes.
- Space infrastructures, such as the ISS.
- Orbiting vehicles, such as, for example, ESA's Automated Transfer Vehicle ATV.
- Space planes, for example Scaled Composite's SpaceShip which Virgin Galactic intends to commercialize tourist flights in the first layers of extra-atmospheric space.

Because of its size, a space program is generally an industrial program whose realization is the result of many technologies which altogether form a *system*, built by many industrial participants who make up an *industrial group*.

In complex space programs, the industrial group is then legally and industrially represented by a sole industry called the *Prime Contractor* which becomes the only interface with the customer to supply the product.

The combination of these two components which characterize a space program makes for a generally complex and risky enterprise, whose costs and duration have highly variable project parameters despite estimates and accurate forecasts during the design phase.

Clearly, these two parameters are intrinsically related not only to technological but also to the political, strategic, and economic aspects of a space project.

Every space program is divided into two macro areas for its development and operations:

1. The space segment
2. The ground segment

The space segment is physically the vehicle which flies into space; the ground segment is made up of equipment on ground during the operational life of the program for use on the space segment (for example, reception terminals for television programs or satellite navigators for cars), or to control spacecraft (for example, satellite stations for telemetry and remote control).

The link for realizing the two segments of a space program is the system activity.

Therefore, the term system can be broadly defined as the capability of managing the realization of a space program through engineering and is an essential component for already multiple competences required ranging from technical to economic and even human resources.

2.3. Implementing Space Programs

A space program includes two main phases and a start-up decision is taken in the middle of the program:

1. The phase at the beginning: identification and conception of the mission, including the analysis of products/technologies to be used and the various cost/time estimations.
2. The phase after the decision: the development and installation of the system.

Program Definition

In the first period the mission is identified and therefore the requirements to be satisfied are drawn down (for example, the realization of a new cryogenic propulsion motor to increase the performance of a launcher to maintain competitiveness on the market).

In the first phase it is crucial to identify the preliminary project, that is to say the conception of space technologies/products to use, if in existence, or to be developed, if they are not available, to implement the mission.

In Figure 2.2, an example of requirements matrix is given which basically reports the subsystems and essential systems to be considered during the processing of the preliminary project.

The starting point is a preliminary industrial project to implement a program, i.e., the analysis of a development plan of a mission which identifies the necessary products, associated risks, available technology and technology to be developed (which enter into the associated risks category), industrial competences to involve, estimate of development time and realization costs.

The decision-making context for implementing the program is therefore essential. The most wide-ranging political, economic, strategic socio-cultural, industrial and scientific and other factors can influence the decision whether or not to start up a space program, be it government-funded or commercial.

In each case, once the elements of the project and the decision-making context are analyzed, what happens next is the negotiation phase, i.e., the phase needed to convince the customer to decide to invest in the program.

Generally, innovation is almost always essential for the positive acceptance of a space program and an innovative mission can fulfill new needs and requirements such

	LAUNCHERS	SATELLITES	SPACE MANNED ORBITAL STATIONS	MANNED REUSABLE SPACECRAFTS	SPACE UNMANNED ORBITAL VEHICLES
SYSTEM					
System engineering	■	■	■	■	■
Project control	■	■	■	■	■
Quality assurance	■	■	■	■	■
Integration & Test	■	■	■	■	■
Operations	■	■	■	■	■
GROUND SEGMENT					
Operations	■	■	■	■	■
TT & C	■	■	■	■	■
Logistics	■	■	■	■	■
Maintenance				■	
SPACE SEGMENT					
Structures & Mechanism	■	■	■	■	■
Aerodynamics	■			■	
Thermal	■	■	■	■	■
Aerothermal	■			■	
Propulsion					
Navigation				■	■
Guidance	■			■	■
Control	■	■	■	■	■
Orbital Attitude Control		■	■	■	■
Power Generation					
Fotovolthaic		■	■	■	■
Chemical	■	■	■	■	■
Thermal			■	■	■
Power Supply	■	■	■	■	■
On Board Computer	■	■	■	■	■
TT & C	■	■	■	■	■

Figure 2.2. Example of requirements and needs matrix.

as increasing already existing availabilities in order to reach new levels of technology (for example, increasing a launcher's performance through the introduction of new propulsion technologies). On the other hand, however, the innovation component is also the bearer of future technological development risks and use risks.

For example, the realization of an onboard antenna for a large low-frequency satellite, over ten/fifteen meters, can be a commercial advantage for the future managers of the satellite in terms of greater number of users who can be reached by the service. However, it could also cause delay risks in the development or worse yet, malfunctioning during its operational life if the antenna technology has not been previously tested by the industry called upon to realize it.

Since a space program is frequently the original integration of new technologies, its success depends on the correct definition of the mission's specifications which must be applied in an extremely accurate manner. Its success also relies on the correct identification of industrial products to be developed whose technologically innovative contribution must be appraised carefully and realistically through the forecast of development risks. It also depends on the correct definition of the program's organization, its duration and costs.

The process which identifies levels of technological risk with the use of products/components of a space system is called "TRL scale" where TRL is the acronym of "Technology Readiness Level." TRL is a methodology for measuring the technological maturity of a component or product, including the final subsystem element. This measurement is essential for understanding the level of technological risk to which the system is subject.

The TRL scale is made up of nine levels:

TRL 1: Transition of a system derived from pure scientific research to application research. Describes the essential features of a system in basics through mathematical formulae or algorithms.

TRL 2: Applied research. The theory and basic scientific principles of technology are focused on an application area and the analytical instruments for simulation are developed.

TRL 3: Validation of "proof of concept," testing a model of the system to be realized is functioning. Research and development are implemented with analysis and laboratory studies. Technical feasibility is demonstrated by developing models whose representation of the final product is still incomplete.

TRL 4: Realization of prototypes and tests. Testing is therefore performed on scale models that are almost fully representative of the final one.

TRL 5: Validation of the integrated prototype with verification testing of the specifications in an environment which represents the future operational environment as much as possible.

TRL 6: The prototype is developed in "full-scale" and the engineering feasibility is tested with application tests that represent the operational environment.

TRL 7: The prototype is tested in an operational environment (or highly realistic one) with a detailed series of tests. The documentation of the technology produced assumes an established form with the corroboration of testing.

TRL 8: A qualified flight system through testing or demonstrations in operational environment (on ground or already in space). The relative documentation is complete both for training and for eventual maintenance.

TRL 9: The so-called "mission proven" system—that is, already used in operational and application environments in space and has demonstrated its effectiveness with a successful operational experience.

The TLR scale is therefore essential in defining the program since it allows us to determine which and how many products, components or subsystems to be used could need innovative developments or not.

Just as important is the preliminary evaluation to measure of integration of the final system to be realized. Whether it is a satellite, a launcher or a robotic system to be sent to another planet, or even a technologically relevant subsystem, the measurement scale

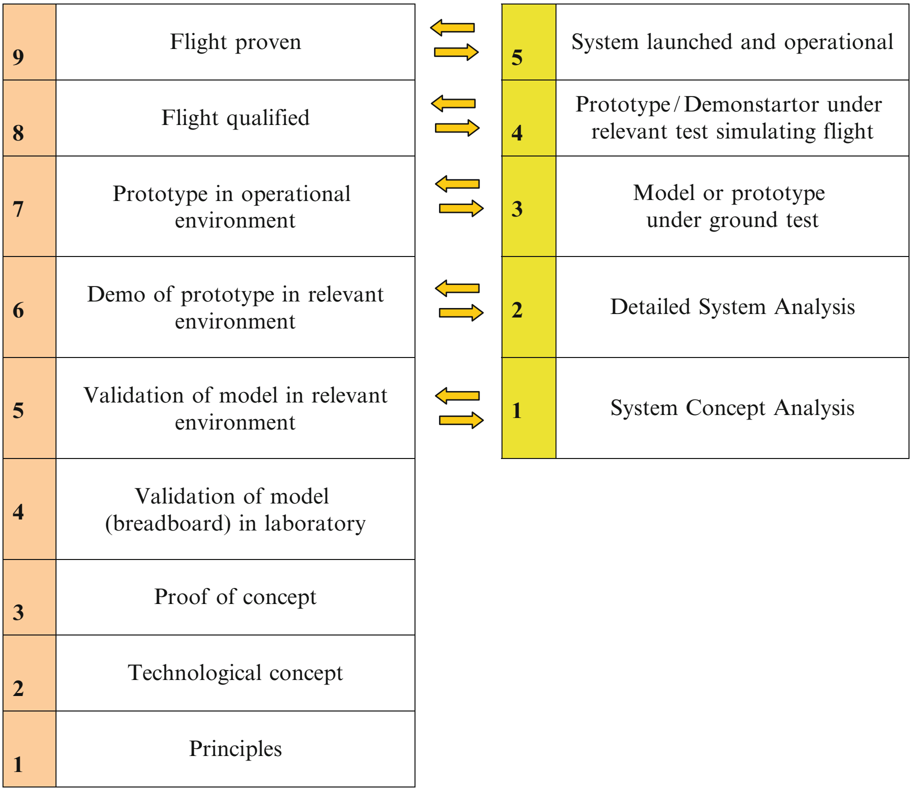

Figure 2.3. Comparison of the TLR and ILR scale.

of the IRL—Integration Readiness Level—supplies an important instrument for understanding the level of difficulty connected to realizing the determined system.

In the same way as the TLR, the ILR also is made up of various scales—five—which indicate the degree of technological confidence:

ILR 1: corresponds to a system where the concept of the whole has been completed
ILR 2: corresponds to a system where the detailed project has been completed
ILR 3: corresponds to a prototype (or a demonstrator called a mock-up) subject to on-ground testing
ILR 4: corresponds to a prototype (or a mock-up) subject to testing simulating flight
ILR 5: corresponds to an operational system, manufactured and already launched

NASA, which introduced the ILR level concepts in 2002, then began modifying them to arrive at a scale of 9 ILR, forming a metric standard called SRL or System Readiness Level which is still in consolidation phase.

Figure 2.3 shows the relationship between the TLR and ILR scales.

Just like most industrial and economic operations, even the development of a space program must, directly or indirectly, lead to an economic objective, such as a return on investment. This is obviously true for private programs with financial objectives, such as commercial telecommunications missions, but generally speaking the same principle should hold true for publically funded space projects (such as the ISS).

More realistically, in these cases very often the objective is mainly industrial strategy and government geo-policy, in which case financial objectives are not necessarily the priority. This leads to undertaking technological risks which are often a characteristic of the agency government programs.

Realization of the Program

In the second phase of realization and implementation, there are the activities related to:

- Negotiation and signature with the customer of a contract in which the customer carefully establishes the objectives to be achieved to the industrial group or Prime Contractor.
- Definition of a document called the “Management Plan,” which is a reference guidelines for the program manager for all development levels, the realization, the implementation and the achievement of the objectives established by the contract.
- Management, which is a dynamic and continuous activity of control and guidance of various development phases.

The contract is signed after negotiation between the industrial group and the customer standing a technical-economic proposal by the group. This proposal usually follows a request for proposals, drawn up and sent by the customer to various potential suppliers.

The contract establishes the objectives which are:

- Technical: observance of specifications, external interfaces, performance and quality of the product to be supplied.
- Temporal: observance of delivery time indicated in the contract during all realization phases.
- Financial: observance of costs indicated in the contract and payment plan which normally follow the time delivery plan.

Should one or more of the objectives not be achieved, whether it be the final delivery or the intermediate one, the contract generally includes a penalty to the industrial group. Generally, these penalties are financial in nature and are incurred when these three objectives are not reached.

Technical noncompliance, failure to observe one or more of the technical objectives of the contract, leads to delays in delivery and cost overruns, which are extra expenses for achieving satisfactory objectives. The costs not included in the contract are monetized by the customer as a reduction of the final cost, or if the final cost does not vary, the industrial group must bear the cost. If the Management Plan has not adequately foreseen, the financial objectives of the industrial group, the program will be negatively affected.

Time noncompliance, which is the delays in the delivery schedule, do result not only from technical noncompliance, but also from a lack of supplies or the inadequate estimate of development time. In each case, the financial fallout will result in a reduction of the final price paid. Financial noncompliance obviously includes the cost overruns caused by the two noncompliances just mentioned.

As stated previously, if the customer does not accept variations to the contract, with possible industrial compensation on the customer’s other programs, the industrial group must take on the cost overruns.

However, if technical noncompliances, being one or more of the technical objectives indicated in the contract, are a result of the customer's modifications and not foreseen in the contract, then the contract is renegotiated and monetized as an increase in the final price.

In addition to the contract, the other main management tool is the "Management Plan," which is the reference document for developing and realizing the program. Every space program requires for almost all its elements, a demonstration of progress with time, on ground and a complete compliance of the product with the specifications of the contract and in general with its space mission.

These demonstrations are theoretical, that is to say numerical analysis and simulations, and representational, and achieved through bench tests.

Both types of demonstrations represent for the entire space program lifetime, tests for implementing the product which once it reaches space cannot be changed, maintained or repaired should it fail to perform properly (except for variations in software which can be modified on ground).

This development approach is laborious and systematic in a space program and must be specified in the Management Plan since the product's functions cannot be reproduced on ground under the same conditions it will be required to operate. Practically speaking, you cannot reproduce the space environment on ground to test all the integrated system as well as the various subsystems. However, thoroughness in the quality of realization, definition and conducting of tests on ground is essential for ensuring the program's success.

The detailed Management Plan is an outcome of the technical definition of the product, the "Make-or-Buy" process of the development plan, i.e., what to make inside the industrial group or what outsource, and when to test and qualify the product.

The Management Plan is based on a three-part breakdown, whose topology must be consistent, made up of:

- A technical three, which is the technical breakdown of the overall system in subsystems and equipment.
- A contract three, which is the breakdown, for example, of the main contract of the Prime Contractor in the subcontracts of lower level suppliers up to basic-level elements.
- A timetable plan, which is a breakdown in linked phases with all the elements making up the elements, subsystems and lastly the overall system.

The elementary module of activities, named elementary Task or Work Package, is located in this last component of the Management Plan.

The Management Plan identifies the drawing up of various reference documents for each contractual stage or level:

- Specifications
- Development and Realization Plan
- Task Description
- Control Plan Quality
- Configuration Plan
- Time Schedule Plan
- Budget Plan

Management Plan

1. Introduction
    - 1.1. General Objectives
    - 1.2. Mission Objectives
    - 1.3. Compatibility matrix
2. Documentation
    - 2.1. Applicable documents
    - 2.2. Reference documents
    - 2.3. Applicable Normative
    - 2.4. Definitions
3. Program Description
    - 3.1. Program objective
    - 3.2. Technical description
        - 3.2.1. Satellite system
        - 3.2.2. Communication sub-system
        - 3.2.3. Propulsion sub-system
        - 3.2.4. Thermal sub-system
        - 3.2.5. Structural sub-system
        - 3.2.6. AOCS sub-system
    - 3.3. Functional tree
    - 3.4. Product tree
4. Organization & Management
    - 4.1. General Organization
    - 4.2. Work Breakdown Structure
    - 4.3. Work Packages description
    - 4.4. Tools for program management
        - 4.4.1. Production Control
        - 4.4.2. Quality
        - 4.4.3. Planning
    - 4.5. Schedule
    - 4.6. Review
5. Quality & Product Assurance
    - 5.1. Configuration Control
    - 5.2. Documentation management
    - 5.3. Product Assurance Plan
    - 5.4. Reporting
6. Acceptance
    - 6.1. Criteria for acceptance
    - 6.2. Non-conformities management
    - 6.3. Final acceptance
7. Cost Control
    - 7.1. General Definitions
    - 7.2. Cost Planning
    - 7.3. Control Tools
    - 7.4. Reporting

Figure 2.4. General structure of a Management Plan for a telecommunication satellite.

Figure 2.4 provides a general chart of a Management Plan for a telecommunications satellite.

With the Management Plan the program managers have at their disposal a systematic tool for controlling the progress of the program and for managing it properly with the aim of achieving the specified objectives through:

- Continuous control, also in real time, of the differences for the realization in progress, measured appropriately, and the state of development foreseen by the Management Plan at that time.
- The analysis of the reasons for these differences up to the manager level for basic equipment.
- The analysis of appropriate corrective actions, the fastest, most effective and economical for putting the means and actions into place for eliminating these differences, for example reorganizing the plan, mobilizing other resources, or using program margins.
- Updating the Management Plan for complying with development reality and phase it correctly with subsequent control.

Performance, timetable, and costs are closely linked in program management through the industry's internal mechanisms. It follows that all increases in performance or quality generate delays or cost overruns and all delays generate cost overruns.

This concept must be understood not only for realization beyond contract specifications, but also for a realization which during production seems so successful that the program managers increase its performance in their eagerness to do well.

Increase in costs is definitely the most characteristic and specific overall measure of a space program's "state of disorder."

Program Constraints

The management of a space program is carried out within a tight network of constraints, that is to say obligations and limitations which must be constantly kept into consideration by the program's managers. Several of these constraints and obligations are specific to every space mission; others are generally applicable to all space programs.

Specific Constraints

The definition of the mission and ultimately of the product conceived for its realization are determined not only by contract performance obligations of time and cost, but also by limitations on the available marginstechnically, temporally, and financially.

Margins are variations of nominal project parameters, in which a system, subsystem or device still function properly.

The consistency of these margins can be reduced under overall budget obligations; for example, an industrial group is competing with another industrial group for realizing a program. In this case, the final price proposed to the customer can be dictated by business logic for obtaining the contract and in order to reduce the prices the program's margins may be tightened.

In the absence of program margins, or with reduced margins, the management of the program on the determined objectives is almost always unsuccessful.

The technical margins are a result of the state-of-the-art technologies used in the program and of the competences acquired by the industrial group. Obviously, the greater are the two, the greater the technical margins of the program.

The lack of technical margins definitely harms the product's quality and compromises the mission's success. The development risks of the lack of margins make it difficult to forecast adequately for time and costs.

The lack of time margins (for example providing for critical equipment in the Management Plan with a 10% delay on the nominal delivery time) or cost margins (for example providing for a possible cost overrun on the purchase of critical equipment in the Management Plan) inevitably leads to development noncompliance which is generally not acceptable without downgrading the equipment supply, thereby cutting the program's development plan.

The result in any case is a highly conflicting situation between the customer and the industrial group which can have destructive effect on the program itself and can cause the failure of the project.

Moreover, the decision is to use risky technologies, unqualified or newly developed ones, for the defined mission, it is crucial to provide for appropriate margins in the Management Plan as alternative solutions which can be developed in parallel down the line or solutions using qualified technologies.

General Constraints

General limitations apply to all space programs, such as:

- The special characteristics of the space environment—the physical conditions (zero gravity, cosmic void, solar radiation)—and astrodynamic conditions (Earth's or Moon's pull).
- The characteristics of the industrial group—overall rules and processes typical of the space sector (for example, the rule of Just Return in Europe, or exclusive alliances in the business world….).
- The general application rules which concern the sector; for example, the ITAR law of the US Department of Commerce which since 1998 considers every mechanical or electronic equipment made in the USA for onboard space systems, to be an armament, limiting the purchase and use by American and non-American industrial groups.
- Social and professional behaviors. Because of their nature, space programs are frequently multinational and for this reason there are permanent problems related to national interests that do not always coincide with those of the program itself. Moreover, because of their complex and multinational nature, space programs often give way to a tendency to spontaneous disorder which is inherent to all collective human activity, especially the most complicated ones.

2.4. Start-Up of a Space Program

As already stated in Chap. 1, a space program generally has characteristics such as international size, major investments, long-term realization (more than a minimum of 2/3 years) and also long operational time (over 10 years) compared to technological developments, the impossibility of repairing in orbit and finally the need of a highly specialized industrial sector.

These elements show the importance of accurate and in-depth preliminary analyses to reach the decision to start up a space program with clear and justified reasons.

The decision-making process is generally as follows (Figure 2.5):

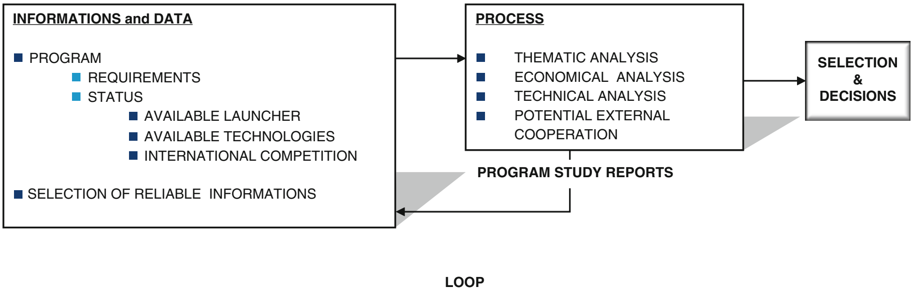

Figure 2.5. General chart of decision-making process for a space system project.

The objective is to establish a project dossier which will be presented to the decision-making bodies.

In the case of the European Space Agency-ESA, the decision-making body is represented by the European Research Council of Ministers which safeguards ESA's activities. Usually the European Ministers delegate the Presidents of national space agencies to represent them in the ESA Council for approving the programs, but every 3 years there are Inter-Ministerial meetings in which the most important dossiers are examined and eventually approved at the research ministerial level for European countries.

For private industries or mixed public–private companies, the decision-making body is the Board of Directors.

However, two main phases can be identified on the writing of the program's dossier.

Information

This involves defining the context of the program proposal:

- The requirement: basically the potential users, and the strategic and/or commercial motivations
- The state-of-the-art of potential similar programs worldwide
- The existence or not of a system/platform suitable for developing the space product
- The existence or not of an available launcher for sending into the required orbit
- The existence or not of technologies to be used
- The international and/or commercial competition
- The existence or not of potentially competitive systems, but not in the space sector (for example, satellite telephone service versus terrestrial GSM)

In this first analysis a set of information data must be reached that is complete, selected, and reliable.

Definition

It involves carrying out:

- Thematic studies, to adjust the proposed system to specific requirements of scientific or application research
- Economic studies, i.e., market analysis, return forecasts, technical studies, i.e., analysis of the project's feasibility
- Opportunity studies, i.e., strategic analysis concerning the value of the program in a commercial or political framework

- Eventual international cooperation protocols
- Obtain permission to use determined frequency bands for transmitting and receiving from and towards space

Through this process various options can be proposed to the decision-making body on the implementation of a program, the so-called "roadmap."

Therefore, a roadmap is a plan for proposing the implementation of the project. In the following paragraphs the decision-making roadmap is detailed for two characteristic types of ESA space missions which stand out because of their objectives and partially because of the decision-making modalities.

Scientific Missions

The objectives of a scientific mission is to improve the state of knowledge in a research domain, such as astronomy, the study of the solar system, Earth science, life science, and the science of materials.

But the improvement of knowledge is not easily quantifiable as a mere objective, and the evaluation of the scientific value of a program and establishment of different priorities among various missions which involve various disciplines are extremely sensitive responsibilities that must come from the scientific community itself.

The national and international scientific community is made up of professors, researchers, scientists, and industrialists and is a community of competences that have an enormous proactive force. For this reason the programs are selected from numerous mission proposals.

It must also be considered that the selection of a mission, or the type of missions, can have a technological impact, in other terms a return, on the industry which develops the program in question. Scientific mission can sometimes serve as a testing ground for future applications. Technological risks are often taken because of the specificities of the missions which require very high performance for their success.

For example, let's consider the technological returns for an industry which through a scientific mission plans and develops a communication antenna for an interplanetary probe whose link-up specifications involves distant celestial bodies millions of kilometers away; such high project requirements make this product a technological test of enormous impact on all future antennas produced. The technologies developed can give the industry knowledge and a commercial "competitive edge" to use in the future.

For the purpose of the subject of this book, we will refer to scientific missions realized in the framework of the ESA's Science Directorate activities, and which are a reference of the activities in Europe for this sector. What is more, scientific activities were the basis for the creation of ESA itself and are the object of annual obligatory funding by ESA Member States in proportion to national gross domestic product. Obviously this process has been fully derived from the NASA science program selection process when during the 1970s ESA engineers were heavily cooperating with their US counterparts to understand how to deal with the space science.

The selection steps for an ESA scientific mission occur according to cycles which occur regularly according to the chart in Figure 2.6 and can be generally summarized in the following phases:

FROM 2 TO 3 YEARS

PROGRAM SELECTION PHASES	ACTORS	NUMBER OF PROPOSED PROJECTS
CALL FOR IDEAS	Scientific Community	>>10
FIRST EVALUATION	Working Groups Space Science Advisory Committee	~10
FEASIBILITY EVALUATION	Scientific Community ESA Industry	
SELECTION	Science Program Committee	3 to 5
PHASE "A" DESIGN	Industry	
PROGRAM SELECTION	Science Program Committee	1

Figure 2.6. General decision-making model of an ESA scientific program.

- Proposal of various missions by the European scientific community, after a Call for Ideas by ESA (a Call for Ideas is an official request for new ideas and projects).
- Preliminary selection by ESA, according to special Working Groups and S.S.A.C., the "Space Science Advisory Committee," of a certain number of missions.
- In-depth examination of the validity of the selected missions by the Scientific Department of ESA's ESTEC technological center with the European scientific community.
- Intermediate selection by the ESA S.P.C., "Science Programme Committee" made up of representatives of the Member States of national space agencies, of few missions (from 3 to 5). This phase involves the endorsement of the S.S.A.C.
- Preliminary analysis (Phase A) from 1 to 2 years, led by various industrial groups to verify and propose industrial feasibility, costs, and time for delivery.

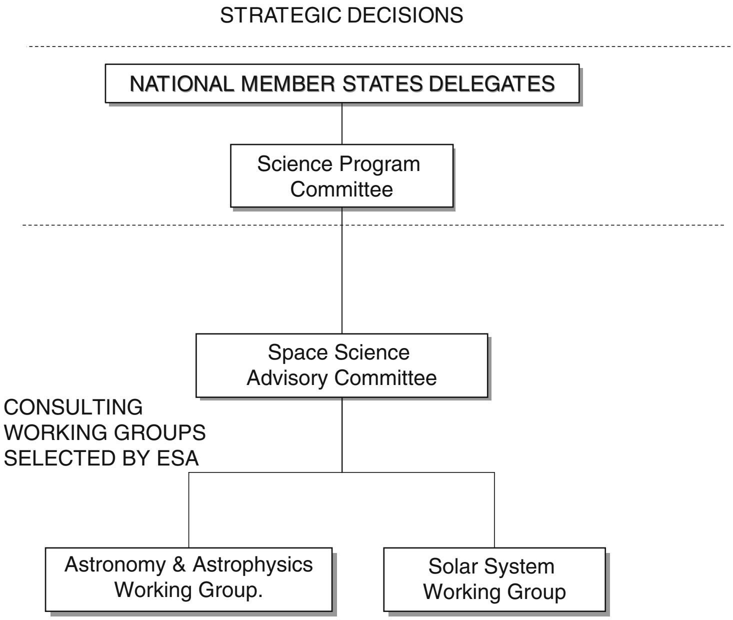

Figure 2.7. Breakdown of decision-making roles for an ESA obligatory scientific program.

- Final selection by the S.P.C. of a mission and start-up of the program with a formal tender to select an industrial group, the Prime Contractor, for the program development and implementation.

Therefore, in the beginning scientific missions in ESA, including large-size ones, remain within the framework of the S.P.C.'s decision-making competence and do not refer to the ESA Council level such as in the case of application programs. But in the last few years even the highest decision-making body of ESA has been involved in programs such as ExoMars for the exploration of Mars program. This is a result of increasing variances between the specifications of the mission (issued by the S.P.C.), the estimates for the development of the industry and the real budget possibilities of ESA.

In Figure 2.7 the roles of various Working Groups are clarified better and their breakdown, for the obligatory scientific program (astronomy and solar system).

Application Missions

The space applications usually include telecommunications, Earth observation and weather forecasting, navigation and satellite localization. In each case they can be divided into two main categories.

Operational Missions

These are space missions where the use of related technologies has reached a level of maturity that can now be integrated with user means, both professional and private. For example, there are weather forecasting applications which are used by government

users, public services or administrations for local, national or international forecasts; DTH "Direct-To-Home" television broadcast services which are used by millions of private users in Europe and in the world through pay subscriptions with service providers.

The requirements these applications fulfill are generally well regarded by users who sometimes, in the case of government users, can be the basis for the origin of the space program acting as decision makers and main or sole investors.

In the case of satellite television broadcast in Europe, for example, the start-up of satellite programs related to two service providers, Eutelsat and SES-Astra, illustrate this situation well.

Eutelsat was established in the 1980s as a European government organization, as the major national telecommunication companies, which were publicly held at the time, subscribed to them. It benefitted for its start-up of the service of the technological developments realized by ESA, through the satellites manufactured by European industry for ESA and a broadcast monopoly on various European territories. This was obviously due to the needs for the Member States who invested in ESA to ensure a return on investment. Then with time, the organization developed into a private business with private and nongovernmental shareholders and today it has been solidly established on the commercial market.

SES-Astra, on the other hand, clearly began as a commercial venture and therefore based itself on private initiative, which in the 1990s decided it was a potential advantage to invest in the DTH application in Europe.

European weather forecasting also followed a similar approach to the one followed in telecommunications and created Eumetsat, a European government organization which includes national weather forecasting services as shareholders and began to use specific satellites built by ESA.

However, in the case of ESA's operational application missions, the decision-making mechanisms are not the usual ones of business initiatives, where return on investment is the priority for starting up a program, but tend to introduce technological innovations that can bring about developments which lead space systems towards the highest possible TRL and ILR levels and therefore can attract the future interest of business firms.

Figure 2.8 illustrates a type of decision-making model for a mission of this type and refers to a generic Earth observation mission adopted by ESA within the framework of the Global Monitoring Environment & Security-GMES program.

Pre-Operational Missions

A pre-operational mission has different features since the evaluation of innovation component and the experimental component are significantly high, but at such a level as to allow the start-up of operations to validate subsequent operational missions.

The general model for a mission of this type is illustrated in Figure 2.9 for a generic example of pre-operation experimentation in orbit of an Earth observation satellite.

It is important to observe the emphasis which should be put on thematic analyses, the studies that define the mission and for this reason the type of onboard instruments to be developed to respond to the mission requirements.

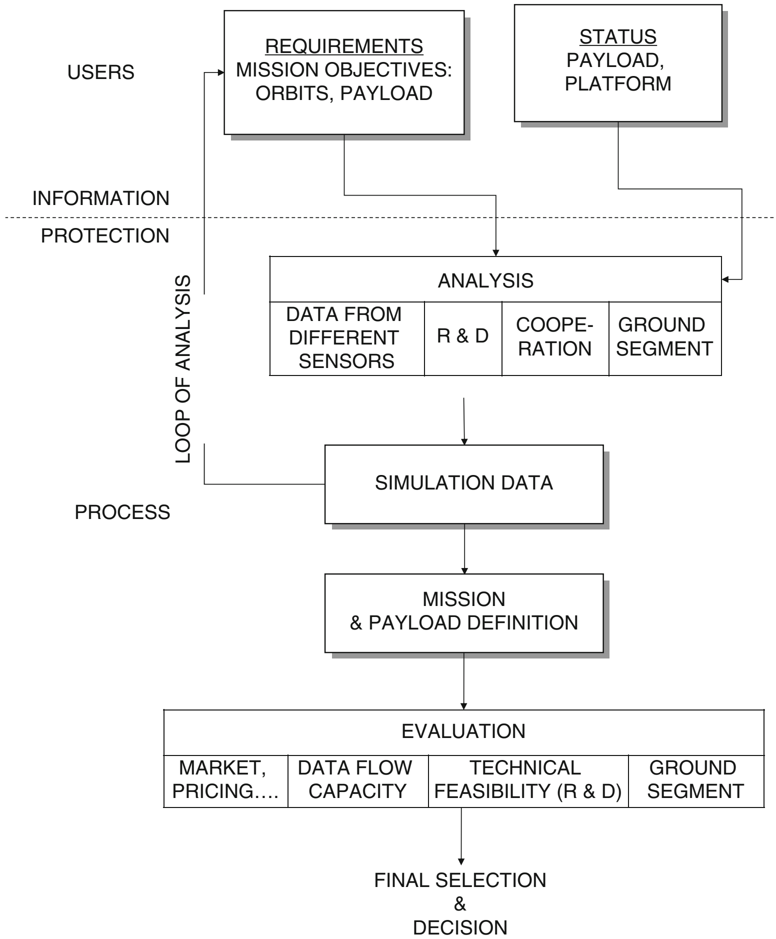

Figure 2.8. General decision-making model for an operational application program of ESA for Earth observation in the GMES (Global Monitoring Environment and Security) program.

Beginning with a requirement, or a series of requirements, such as the need to control the dynamics of vegetation or the surface of oceans for example, the thematic analyses must respond to questions of this type:

- Which parameters should be measured and how precisely?
- How often should the measures be repeated?
- Which sensor must be used to offer the best solution?

To give appropriate answers it is often necessary to use onboard or air-transported instruments to carry out effective measurements, experiments, and research for experimenting measurement campaigns and prepare future users to the use of operational data.

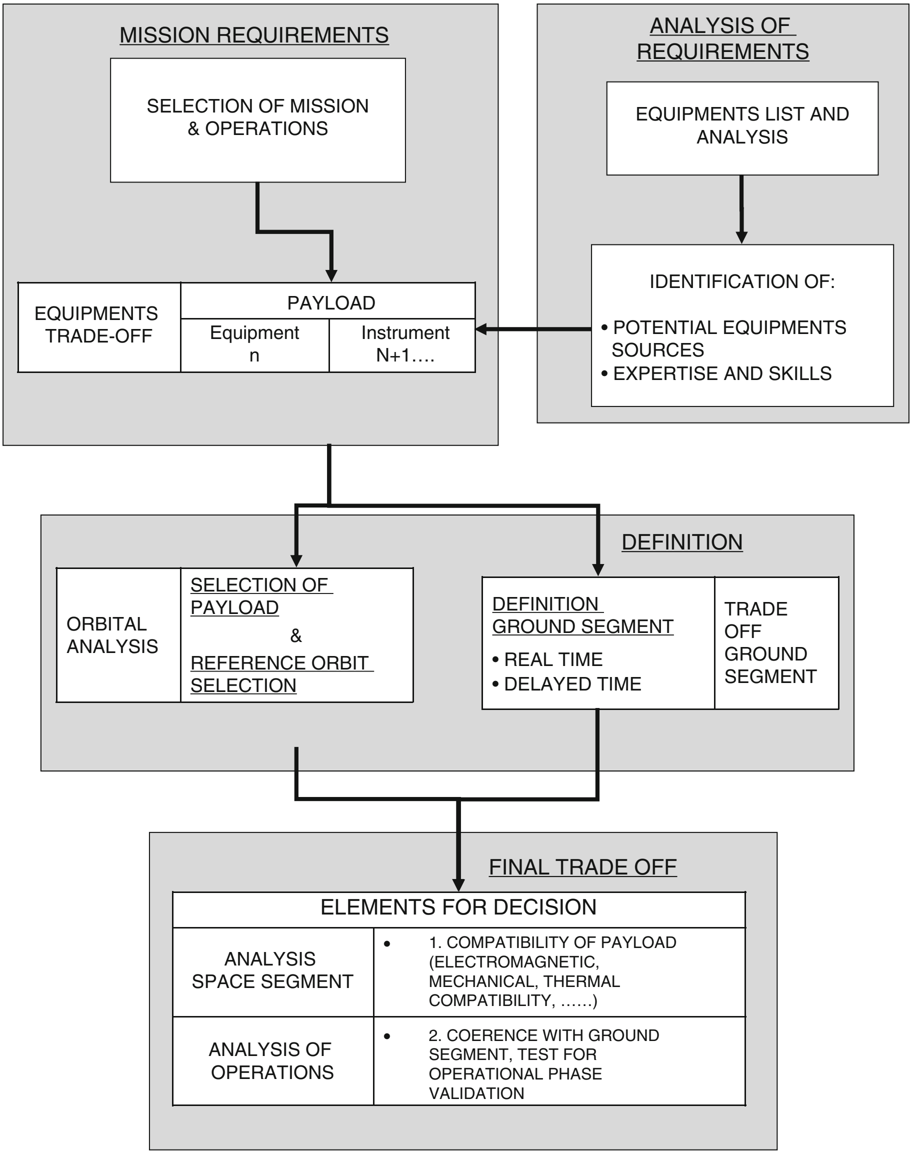

Figure 2.9. General decision-making model of an application-experimental ESA program.

The results of these preoperational campaigns must then be used to re-direct and improve the objectives of the mission.

In Figure 2.9 the definition process of an application-experimental mission is charted. A consultation has already been done which identified with some instruments suitable for fulfilling mission requirements.

As stated previously, in starting up this type of mission, it is not certain that the TLR levels of certain sensors or instruments are adequate, but it is for these reasons that the agency implements a program with those instruments to create technological and industrial innovation.

Commercial Programs

In the two preceding paragraphs the logics of development of the two types of ESA programs has been discussed. In 1975 ESA was the European agency to have created the foundation for the scientific and industrial programming of space projects. The process which brought ESA to adopt the logics of start-up and management of programs was highly influenced by its interactions with NASA. European experts, during the 1970s and 1980s, worked with their US counterparts to understand the problems concerning the development of space programs and to draw up procedures which were then "assimilated" to the US procedures already in place in those years.

The 1960s had brought well-known space successes to the USA. In the 1980s and 1990s following increasing commercial development, mainly in telecommunications, of satellite systems, the implementation of a commercial program developed decision-making processes which differ substantially from ESA or NASA's government agency logic.

Typically a commercial program has two basic features:

- The need for low-risk technology and low operational difficulty (developmentally and for use in orbit)
- The need for the highest economic efficiency of its system

These guiding parameters are the bases for technological and program choices. This is why a commercial system always involves the development of an already proven system with operational experience, high reliability and long operational life, with low development time and rapid injection into orbit.

As a result, the components are already qualified and tested in orbit and the development of the system does not vary from industrial processes already in place.

It is very rare for a business which intends to use space systems, for example, operators of telecommunication satellites or satellite images, to introduce technological innovations in their systems which would bear risks in the development and launch of the system.

Moreover, very often a commercial operator of satellite systems does not have the staff with specific space technology competences and uses outside consultants (experts in the space sector) who work to define the system and the subsequent control of the program.

The development of a commercial program therefore differs from the ones examined previously and generally consists of five phases, highlighted in Figure 2.10.

In phase 1 the company performs market studies, defines the business model to be implemented, evaluates the technological and economic risk, and essentially draws up its business plan.

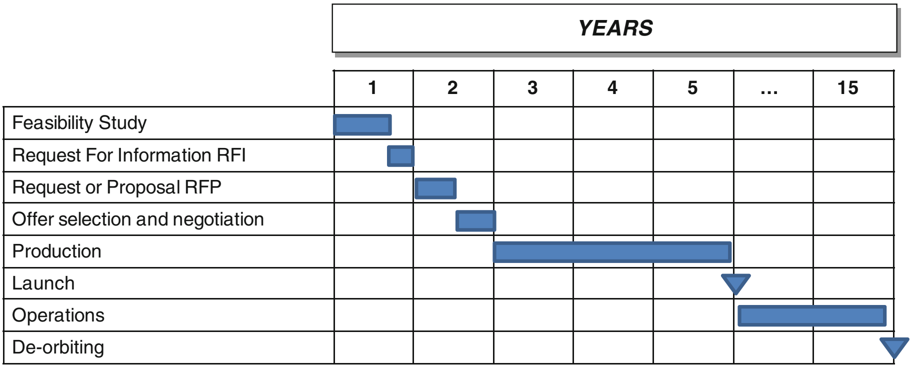

Figure 2.10. General decision-making process timing of a commercial program.

In phase 2 the company sends industrial producers it has selected an RFI, Request for Information, similar to the Call for Ideas mentioned previously concerning the start-up processes of ESA programs.

The RFI contains preliminary but fairly specific requests such as:

- Production experience
- Possible technical proposals to improve the effectiveness of the proposed production cycle
- Preliminary estimate of costs and timetable

In phase 3 the company sends selected industries, which have responded to the RFI, an RFP, a Request For Proposal. At this point the industry which wishes to win the contract to develop the program gives a detailed proposal of the program whose structure will be discussed in Chap. 3 and which does not substantially differ from the one put into place by the industry toward an agency such as ESA or NASA.

In phase 4 the company has selected the supplier, has signed the contract and the production process for the "procurement" of the system begins. The management of the program is the core of phase 4 and ends with the system going into orbit.

In phase 5 the supplier transfers the system in orbit to the customer (the company or agency which authorized the project) and commercial operations begin which last an undetermined number of years generally ending with a deactivation phase, in the case of geostationary telecommunication satellites this phase implies a de-orbitation of the spacecraft. The satellite is essentially moved, with a small amount of residual fuel, onto a slightly different orbit from the one used for operations so it does not "crowd" space.

2.5. Development Phases of a Space Program

Space programs in the world as in Europe were soon organized into *Phases*, corresponding to the development of the life of the program itself.

Once the feasibility studies have been done, the decision to start up a program or not is taken, and then the drawing up of the Management Plan is completed.

The program is finally realized, it is physically launched into space and the services/applications for which the mission was defined are used.

However, given the increasing complexity of space programs the minimum time between the first feasibility studies and launch into space can vary between 28 and 36 months needed for realizing, for example, a commercial telecommunication satellite, or from 6 or even 10 years needed to realize and qualify a launcher. In several cases, we have gone over 15 years, such as for the realization of the ISS.

This long-term time frame leads program managers to detail the timetable of the Management Plan into *Phases* which are finally defined as the development objectives to be followed. The organization of the various activities, objectives and intermediate results into a time framework is indispensable today.

Every passage from one phase to another is authorized by program managers and contractually confirms the technical consistency of the work performed up to that point by the industrial group. In so doing the question of technical choices of the preceding Phase is avoided, unless there are major problems in development.

Logic of Program Control

Because of their size and technological specifications, space programs take many years to achieve with an investment budget of hundreds (and even thousands) millions of euro.

Building in 30 months a large commercial telecommunications satellite with over 50 transponders on board can cost over 300 million euro, including the manufacturing of the satellite, the purchase of the launcher, the insurance and the construction of the ground segment.

For example, the construction and launch of the first four Italian satellites of Earth observation, Cosmo Skymed, cost over 1.2 billion euro in 5 years.

Therefore, it is impossible to wait for the end of a program to verify whether it is satisfactory to the users.

It is necessary to control the program activities to validate technical and economical solutions adopted as the activities develop during the course of the program.

The biggest problem for controlling these activities involves:

- Decisions which influence investment too early in the program (see Figure 2.11)
- Nondeviance from initial requirements

The logic of control can be defined correct if:

- Ensured convergence toward the specified development objective step by step, with cost and time conditions are duly respected.
- Management of a progressive and controlled commitment of the means and resources for developing the program, with choices that should not hinder technical solutions prematurely.
- Consolidated results through the program are achieved to reach the progressive development of the system step by step.
- We provide for a time and financial “reserve” from the beginning called “contingency” or “margin,” as illustrated in Figure 2.12.

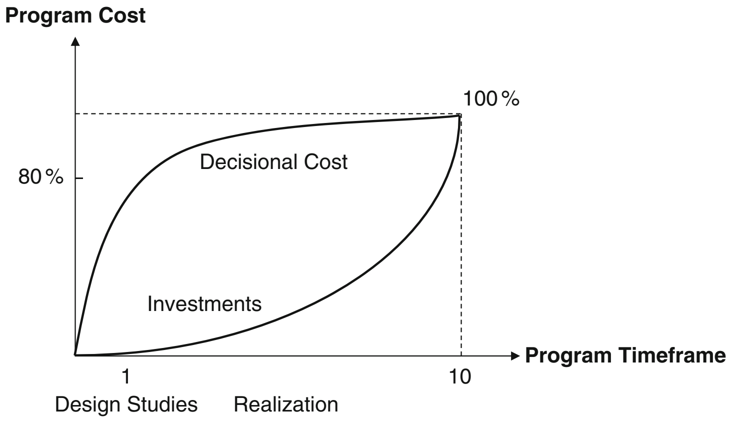

Figure 2.11. General cost/length relation of a program.

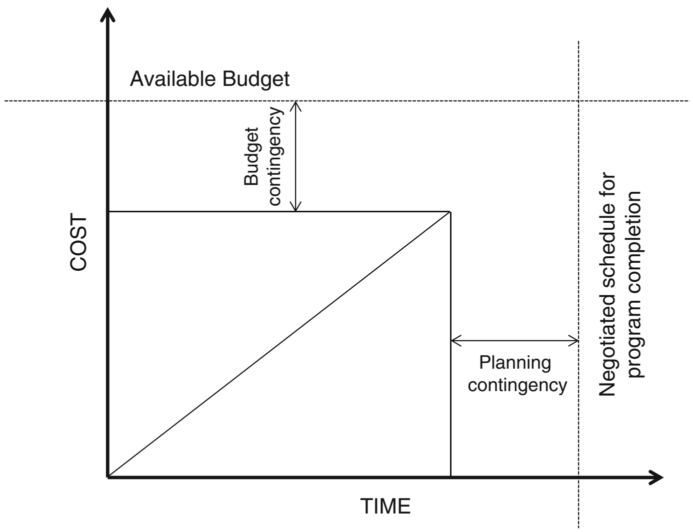

Figure 2.12. Definition of the "contingency" for budget and time management.

This logic leads to subsequent steps approach and key events, called "milestones" which cover various Phases throughout the duration of the program. Each Phase is characterized by a milestone.

Every milestone allows us to:

- Verify what has been developed
- Verify what influences negatively the progress of the program

Milestones are the opportunity for analyzing:

1. Production quality
2. Potential delays or already created ones
3. Actual and future costs
4. Means used and to be used
5. Resources used and to be used

A milestone includes two events:

1. A validation which can be performed by external and internal authorities to the program who give their recommendations on the Phase, in progress or terminated
2. A decision by the program manager on the progress of the activity including the application of issued recommendations

Since the 1960s the USA has felt the need to standardize project logics and this process was established with the drawing up of a series of requirements called the NASA Military Standard. Through these standards the customer and contractor possessed the specific program procedures to be followed.

Beginning in the 1970s, after the inception of ESA in 1975, a similar need was felt in Europe. The ECSS, European Cooperation for Space Standardization, standard was developed and internationally recognized and assimilated to the US Military Standards.

The ECSS are subdivided into three levels:

1. Series E, engineering
2. Series Q, product quality
3. Series M, management

And have three different levels of detail. In the first there are the standards for determining strategies and requirements, in the second management functions and objectives and in the third level the guidelines for reaching level 2 are outlined.

Figure 2.13 shows an overview of ESA's ECSS.

Let's go on to define the various program Phases. Each Phase ends with a "review," a large meeting in which a committee ("board"), with specific program managers and experts, analyzes the results achieved and on this basis defines action for control and recovery, and deciding whether to proceed or not to the next Phase.

Phase 0, or Mission/Project Concept

After a Call for Ideas generally various projects for missions are examined and the managing authorities of the program select only few of them for a more in-depth analysis, the Phase 0.

The objective of a Phase 0 is to gather the elements which allow to judge formally the size of a program, level of industrial, technical and financial requirements deemed necessary for the mission's requirements.

Consequently, in Phase 0:

- The mission must be defined and its objectives clarified.
- One or more systems that can achieve the mission must be identified as well as the major problems to be resolved.
- An estimate of the means, timetable, and resources necessary must be drawn up.

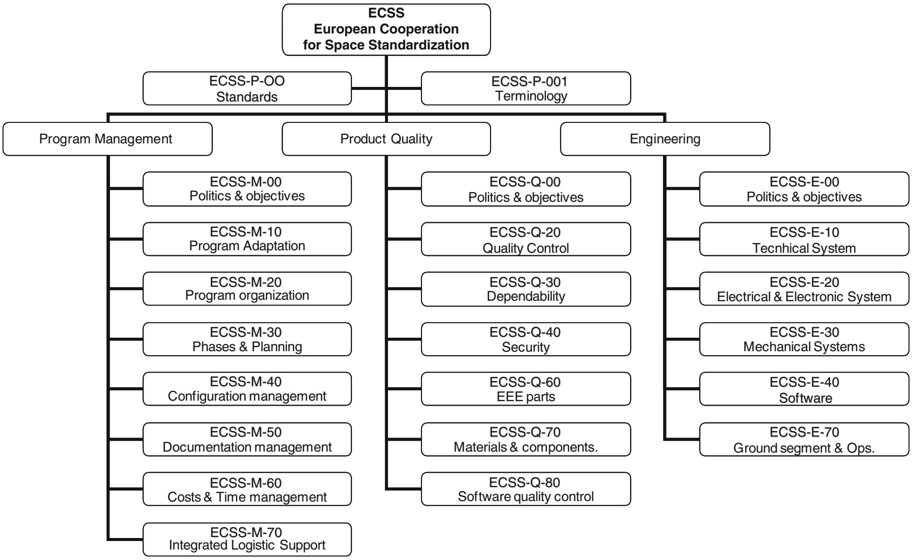

Figure 2.13. Overview of ECSS, European Cooperation for Space Standardization.

Phase 0 is executed with a preliminary project which must allow decision-making authorities or the customer to follow or not follow through with the analysis of the mission under consideration.

A positive decision at this point is a key moment for the program, it is a decisive step and really begins the program.

The final review of the Phase 0 is called MDR, “Mission Definition Review.”

Phase A, or Feasibility Study

Usually, following Phase 0 if the proposal has drawn enough interest for its development, Phase A is begun for a more in-depth analysis.

Therefore, the objective of Phase A is to evaluate the program’s feasibility under technical aspects, cost and time, leading to a more concrete identification of risks associated with the development of this program.

Therefore, during Phase A:

- The objectives of the proposed program are clearly stated and the mission requirements duly identified.
- The financial and strategic analyses are also detailed.
- Technical modalities for realization and implementation are analyzed to synthesize the main technical difficulties to be overcome and to estimate the possibility of concretely achieve the objectives of the program.

At the end of Phase A a technical-financial report must be drawn up as well as an analysis relative to the program’s implementation which must contain:

- A development plan proposal, “Development Plan,” with the technological R&D plan that will be necessary for developing the program (for example, for the European program Galileo for satellite navigation, the Development Plan also

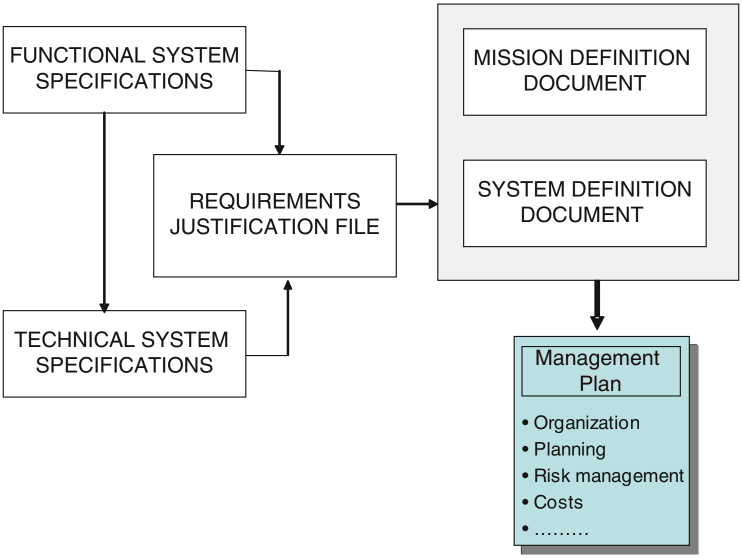

Figure 2.14. Document planning of Phase A.

foresaw an R&D plan relative to the development of onboard atomic clocks whose technology was present in Europe but not developed for space flight).

- A proper and realistic evaluation of costs and time for realizing the program, identifying margins of uncertainty. For example, in the development of a commercial satellite, an incorrect estimate of delivery time causes the customer, i.e., a commercial operator, a loss of return for selling lately the service, and for the industrial group a payment penalty by the customer.
- A realistic project of the financial model of the program, its management organization and related documentation.

Figure 2.14 illustrates the flow of relative documents of various activities which will then be the basis of the final "milestone" of the Phase, the final review. This flow is extremely important for following the program because basic requirements for starting up the program develop from it.

Usually in space programs, at the time Phase A is completed, an initial large meeting is held to review the analyses performed, the PRR "Preliminary Requirements Review."

The decision-making authorities, for example, the customer, whether ESA or another purchasing agency or commercial operator which is ordering a product, participate in this meeting. Then there is obviously the participation of the industrial group which has done the analysis and there might also be present agencies and external resources to the program with a declared expertise that are called upon by the decision-making authority to help evaluate the report.

The results of the review lead to the selection or nonselection of the program, considering the recommendations for modifications and/or variations issued by the members of the review board during their analyses.

Efforts in terms of resources to be used in Phase A obviously depend on the breadth of the program to be implemented. For example, the Phase 0 study of a new launcher can last several months and up to over a year, using dozens of resources, i.e., months of manpower.

Phase B, or Preliminary Definition

The objective of this Phase is to reach a complete definition of the program. The start-up of Phase B is already an important choice by decision-making authorities since it validates the technical-financial choices made in Phase A and therefore adopts the technical options which form the basis of the program.

The start-up of this Phase generally indicates the taking into charge of the program by its developers and because of its importance a significant amount of work is performed, especially:

- The analysis and definitive choice of the system/product to develop in the program. For this reason there is an evaluation and discussion of concrete technical choices. Once they are completed they will make up the specifications of the system to be developed.
- The definition of the system architecture and of the functional distribution of the various subsystems.
- The definition of the future program with regard to Research and Development.
- The writing of the complete Development Plan, of the number of platform to develop, testing and qualifying procedures and means for these purposes (for example, the detailed definition of mechanical and electrical instruments for testing).
- The definition of the managerial and industrial organization charged with implementing the program, including a detailed evaluation of the means, human and material, which are needed.

The end of Phase B is also subject to a program review, generally referred to as PDR, "Preliminary Design Review."

Frequently, due to the size of the program the financial investment can be heavy also to complete Phases A and B, therefore this phase is subdivided into two or more sub-Phases, called B1, B2….Bn. Each of these phases ends with an intermediate review, referred to as SRR, "System Requirements Review," whose implementation and conclusion are necessary for the start-up of the subsequent sub-Phase.

Generally speaking, B1 is aimed at defining the system's specifications and B2 to subsystem specifications. However, each program may be subdivided into sub-Phases according to different criteria. This method helps a leveraged up-front investment.

In Phase B the program usually mobilizes already enormous amounts of resources and of capital, and the effort made in terms of months/manpower can turn into a complex satellite project (for example, ESA's scientific satellites) with dozens more months/manpower. Even the cost of Phase B reaches 10–15% of the total cost estimate of the program. Therefore, the conceptual choices of this Phase determine 80 or 90% of the program's implementation cost.

Thus, the importance of the decision to continue the program at the end of the PDR of Phase B is evident, since the subsequent Phases will concern the actual implementation of the program.

Phase C, or Detailed Definition

The objective of this Phase is to achieve the implementation specifications.

In this Phase the industrial group is called upon to detail the constitutive parts of the program and the conditions for their realization. Therefore, it is a major industrial operation which involves not only detailed studies, but also models and preliminary testing.

The CDR, "Critical Design Review" comes at the end of Phase C and precedes the realization phase.

Phase D, or Production

During the course of this Phase of the program, the system is built and tested, and its ability to fulfill the mission's requirements for which it was implemented is verified.

Obviously this verification occurs under operational conditions and on a structure which will be used on the mission.

A specific review of operational qualification ends this Phase. Usually, given the complexity and time length of Phase D, various intermediate reviews are necessary and their importance is heavily affected by the launch time deadline.

In programs for developing satellites and launchers, for example, Phase D is broken up into steps with specific reviews, for example, the QR, "Qualification Review," the PCR, "Production Configuration Review" up to the AR, the "Acceptance Review," which take stock of the situation and which are mandatory passages (milestones) which must be passed for the progress of activities which in fact end with the launch of the system into space.

The decision taken by decision-making authorities to go to the next Phase, following a positive "Acceptance Review," concludes the end of the program's development.

Sometimes Phases C and D are "unified" under the term Phase C/D.

Phase E, or Operations

The space system developed by the program is launched into space during this Phase and operates by supplying services for which it was designed.

The ORR, "Operational Readiness Review" provides evidence of the system's function and authorizes the start-up of the launch campaign which ends with the FRR, "Flight Readiness Review" which gives the definitive and final approval for launch into orbit.

Usually, for a telecommunications satellite, the ORR takes place 2–3 months before the launch and starts up the launch campaign, the sending of the satellite to the launch site for final test operations, loading of fuel and final integration with the launcher. The FRR takes place the day before the launch and after its positive conclusion the launcher is loaded with fuel and sent to the launch sequence.

Once in orbit, a scientific satellite's instruments begin to operate and transmit the data for several years, a telecommunications satellite begins to receive and transmit radiofrequency signals on the geographical area it covers for over 10 years. A launcher instead puts into orbit and releases a satellite it is carrying on board after less than hour from the launch time to Earth, and so it ends almost immediately its operational Phase.

It should be noted that in the case of recurrent production systems, mainly referred to commercial satellites or launchers of the same version, the functional data gathered

during the course of Phase D often lead to significant modifications of the system during its lifetime.

Here is where the program introduces modifications at every level in its Development Plan and this leads to a new process in Phases, obviously noticeably accelerated compared to the initial one, which observe the logic foreseen, however modifying elements or subsystems of the original development process.

This analysis can lead to Phase F, or final placement, with the conclusion of the operational life of the system and its deactivation.

A synthesis of the Phase process is summarized in Figure 2.15. In this planning there is a variable "time" frame axis inserted, i.e., the measure of the duration of the project as a nominal duration of the program.

The project flow which is defined above does not only apply to the program's Prime Contractor, but in cascade fashion involves all the sub-suppliers for which the review process is managed directly by the Prime Contractor. However, the approval for the advancement and payment is usually delegated to the main customer. This is the common practice for ESA programs.

Obviously, at the level of equipment and subsystems, the project flow must come before the system and critical reviews must be done before the program Phases, otherwise the impact on overall planning would become unmanageable.

Figure 2.16 illustrates a functional hierarchy of the project's responsibility as an example of this.

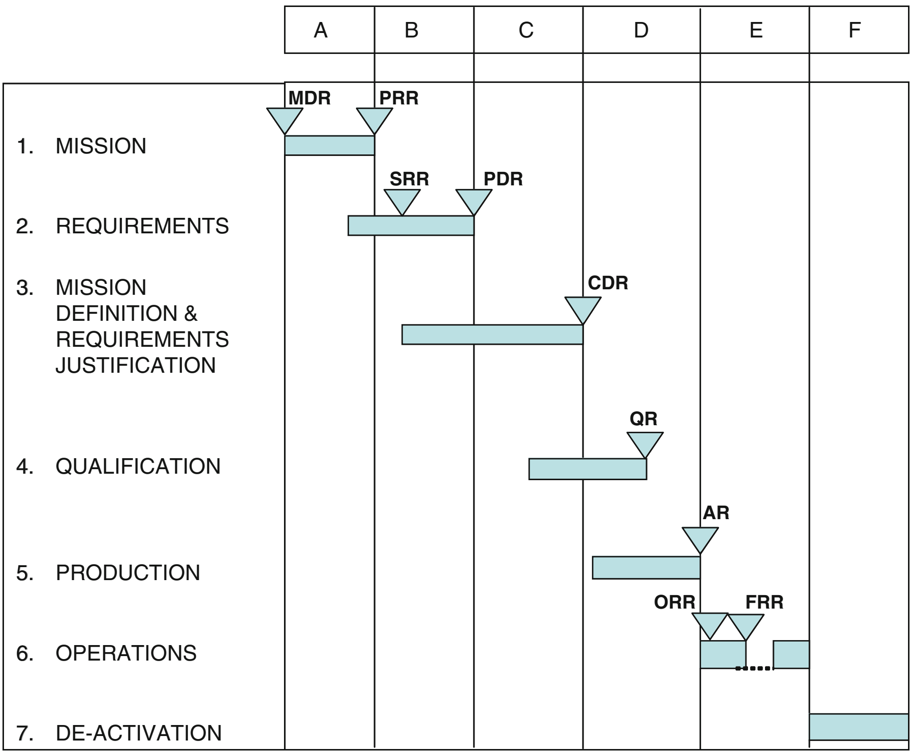

Figure 2.15. General model of the program Phases.

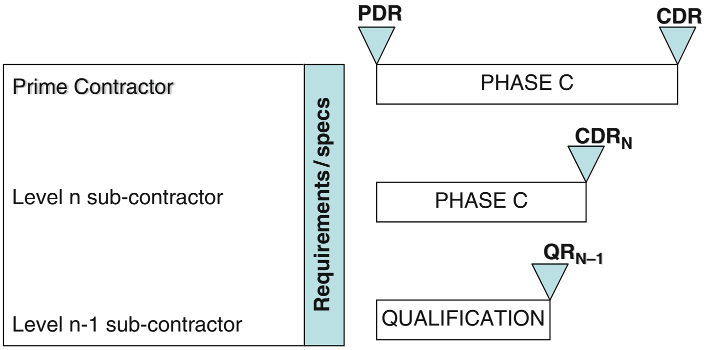

Figure 2.16. Example of the hierarchy of program responsibility.

There is a difference between the methods used for institutional programs, such as ESA's and the practice for commercial programs for which technological innovation, with greater risk, are usually neglected.

However, even in commercial programs the ECSS standardization model is used as a model, because the quality control and production flow represents in any case a guarantee of product reliability for the customer.

Advantages and Limitations of Subdividing the Program into Phases

The organization of a program into progressive steps forward and intermediate decision-making steps have an undeniable advantage in terms of:

- Criteria and progressive definition of the activities to be developed and the necessary means.
- Engaging means and necessary resources only at the right moment.
- Control by responsible authorities of the state of advancement and possibility of implementing more effective management techniques.

On the other hand, limitations are present essentially in the difficulty of describing in stable and standardized models the complete process of development of a space program which develops in a government, industrial, and commercial context in constant evolution.

The creation of Joint Ventures or industrial mergers, intergovernmental or commercial agreements are variables which can influence the life of a space program which lasts many years.

Obviously, the program managers must organize activities with thoroughness and logic to predispose a solid and orderly organization of the Management Plan as much as possible. However, they have to include flexibility in the organization to adapt to potential evolutions of the context.

Quite often, this requires imagination, common sense, and notably human and organizational flexibility, which can seem contradictory with the notion of engineering organization for rules and procedures.

In doing so, managers can therefore be free to design the name and type of the organization in Phases within the Management Plan in broad terms. Next to the letters 0, A, B, C, D, E each manager can, according to the program and the circumstances under which it is developing, add contents to the Phase according to logic and specific development consistency.

For example, it should be noted that in a space program various aspects converge, in making an organization complex by distinctly dividing it into Phases.

Technically speaking, it is often necessary to override Phases because of development reasons. A Phase C/D can begin with several subsystems during Phase B of the program due to supplies or the beginning of long-term work (realization of building a launch base for example). In another case, several technological developments which should usually end in Phase B can continue on during Phase C/D.

The way different parts of a program advance are almost always different. For example, for a commercial satellite program the definition of Phase B for the ground segment development (reception terminals, for example) must wait for a detailed configuration of the space segment (for example, onboard payloads), which cannot take place during Phase C/D.

Finally, the same decision-making process does not always express itself in a synchronistic manner in time with the program's development since during the course of its development this requires a significant amount of intermediate operational decisions which overall will make up those technical choices to be evaluated in terms of each Phase in the appropriate review.

It is the task of the Program Manager to harmonize all these activities by coordinating them in time.

The Program Reviews

The program reviews are meetings of limited duration (from 1 day to several weeks) held at pre-established times in the Management Plan and during which the program activities are presented, examined, and criticized.

The program review is a shared tool for controlling and managing the program for decision makers and the Program Managers.

The objective of the program review is to:

- Consider program activities at different time steps.
- Support decision makers and Program Managers in controlling the state of advancement of activities.
- Give decision makers and the Program Manager tools for evaluating if the activities allow the continuation of the program or its realignment.

For this purpose, the method applied to this review is the following:

- Take appropriate distance from usual activities (meeting place, type of behavior) to examine the elements of the program.
- Support different positions without the restriction of discussions and debates.
- Call upon technical and managerial experts outside the program who can introduce new elements into the program, highlighting anomalies or improvements.

Every review is usually organized so that a “review group” made up of a certain number of people not necessarily directly involved in the program evaluate it by examining documents and attending presentations by the Program Managers and industrial group.

The review group, which elects its President, issues “observations” and “recommendations” written on standard forms which are sent to decision makers and the Program Managers for appropriate evaluation and actions.

An essential aspect is the organization of the review and it is useful to distinguish that there are two important periods in the life of a program for which reviews should be set up at different levels (system, subsystem, and equipment) in different manner.

The first period is the definition of the program when activities involve study and concept-making, and the subsequent reviews can “diverge” to various levels (system, subsystem, equipment), but are conducted chronologically in increasing order.

The corresponding Phases are 0, A, and B.

The second period is the program development when the activities involve building and testing, and the subsequent reviews “converge” at all levels towards the reviews of the system.

The corresponding Phases are C and D.

The reviews can have various forms according to the program function and organization of the review group. However, given the nature of space programs, these meetings always maintain a certain formality of procedure that is appropriate to the limitations of diffusion and confidentiality which shared technical information often requires.

In review groups, one must always keep in mind that the objective is not to take the place of the Program Mangers, but to get the best possible evaluation of how the program is progressing.

Through specific numbered technical notes, issued by the industrial group, the review group takes notes of the problems which have been brought up for subsequent discussion and possible shelving. Should a problem not be shelved it gives way to an action for the authorities to verify and subsequent closure of the problem.

The review group, guided by its President, steers the meeting, establishes the agenda, gathers technical notes of the problems to be resolved, organizes analyses for necessary solutions, and synthesizes the activities performed.

His role is essential for presenting to the decision makers observations and final recommendations during the concluding meeting of the review.

It is not an easy task to gather competent, motivated and available people for a review group.

Decision makers and the Program Managers have to show common sense and sharp skills for choosing and assembling the right people, many of whom are not directly involved in the program, who can truly understand the technical choices made and understand possible development problems.

This is the actual basis of the review: to ask competent questions and perceive possible problems.

Therefore, for a successful review one should have a well-prepared review group, the right mix of internal, external and people close to the program and definitely a major personal attachment to the activity.

The main risks of the Review are almost always due to excessive formalism where form is criticized and not the real issues involved. Another risk is superficial examination of the relevant aspects of the program in a limited time frame.

One of the main tasks of the President of the review group or its steering committee, the “board,” is to minimize these risks.

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